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Physical oceanographic conditions in NAFO Division 3P during 2003 - possible influences on the distribution and abundance of Atlantic cod (*Gadus morhua*)

Conditions océanographiques physiques dans la division 3P de l'OPANO en 2003 – effets possibles sur la répartition et l'abondance de la morue de l'Atlantique (*Gadus morhua*)

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Abstract

Oceanographic data from NAFO Division 3P during the spring of 2003 are examined and compared to the previous year and the long-term (1971-2000) average. Temperature measurements on St. Pierre Bank show anomalous cold periods in the mid-1970s and from the mid-1980s to mid-1990s. Beginning in 1996 however, temperatures started to moderate, decreased again during the spring of 1997 and returned to more normal like values during 1998. During 1999 and 2000 temperatures continued to increase, reaching the highest values observed since the late 1970s in some regions. During the past 3 years however, temperatures have cooled significantly to values observed during the mid-1990s by the spring of 2003. In fact, the average temperature for NAFO Division 3P during the spring of 2003 was the coldest observed in about 13 years. The areal extent of <0°C bottom water increased significantly from the mid-1980s to mid-1990s, but decreased to very low values during 1998-2000. During 2001 to 2003 however, this area increased to values observed during the cold years of the early 1990s. Since 1995, the areal extent of bottom waters with temperatures >1°C has been increasing reaching pre-1985 values during 1999-2000, but during 2001-2003 this area decreased by 25%. On St. Pierre Bank <0°C water completely disappeared during the warm years of 1999 and 2000. It has since increased to between 20-30% areal coverage during 2001 and 2002 and to over 90% during 2003. In general, temperatures during the spring of 2003 decreased significantly over values observed during the past several years. The most evident trend in the numbers of cod caught per set during the multi-species surveys was the high number of zero catches in the <0°C water on St. Pierre Bank and regions to the east of the Bank, mainly from 1985 to 1998 but also from 2001 to 2003. During 1999 and 2000 larger catches became more wide spread over St. Pierre Bank as cold (<0°C) water disappeared from the area. In general, during all surveys most of the larger catches occurred in the warmer waters (2°-6°C) along the slopes and areas to the west of St. Pierre Bank. In addition, variations in the estimated abundance and biomass of cod from the RV surveys in strata with water depths <92 m are significantly correlated with bottom temperatures for that depth range.

Résumé

Nous examinons les données océanographiques obtenues dans la division 3P de l'OPANO au printemps de 2003 et les comparons à celles de l'année précédente et aux moyennes à long terme (de 1971 à 2000). Les mesures de température effectuées sur le banc de Saint-Pierre montrent des périodes anormalement froides au milieu des années 1970 et du milieu des années 1980 au milieu des années 1990. Les températures se sont légèrement réchauffées en 1996, puis ont diminué au printemps de 1997 et sont revenues à la normale en 1998. En 1999 et en 2000, les températures ont continué de se réchauffer, atteignant les valeurs les plus élevées observées depuis la fin des années 1970 dans certaines régions. Toutefois, depuis trois ans, les températures se sont considérablement refroidies, atteignant au printemps de 2003 les valeurs observées dans le milieu des années 1990. La température moyenne dans la division 3P au printemps 2003 était la plus froide depuis environ 13 ans. La superficie couverte par de l'eau de fond de température inférieure à 0 °C a augmenté considérablement du milieu des années 1980 au milieu des années 1990, mais elle a diminué à des valeurs très faibles de 1998 à 2000. De 2001 à 2003, cette superficie a augmenté pour atteindre les valeurs enregistrées lors de la période froide du début des années 1990. À partir de 1995, la superficie couverte par de l'eau de fond de température supérieure à 1 °C a augmenté, atteignant les valeurs d'avant 1985 en 1999-2000, mais de 2001-2003, cette superficie a diminué de 25 %. Durant les années chaudes de 1999 et de 2000, l'eau de température inférieure à 0 °C a complètement disparu du banc de Saint-Pierre, mais en 2001 et 2002, cette eau couvrait de 20 % à 30 % de la superficie du fond, et cette valeur a dépassé 90 % en 2003. En général, les températures enregistrées au printemps de 2003 étaient considérablement plus froides que celles observées depuis plusieurs années. La tendance la plus évidente de la quantité de morues capturées par mouillage d'engin lors des relevés plurispécifiques était le grand nombre de captures nulles dans les eaux de température inférieure à 0 °C sur le banc de Saint-Pierre et dans les régions à l'est du banc, surtout de 1985 à 1998, mais aussi de 2001 à 2003. En 1999 et en 2000, les captures plus importantes se sont répandues sur le banc de Saint-Pierre à mesure que l'eau froide (< 0 °C) disparaissait de la région. Lors de tous les relevés, la plupart des captures importantes se produisaient généralement dans les eaux relativement chaudes (de 2 à 6 °C) le long des talus et dans les régions à l'est du banc de Saint-Pierre. En outre, les variations dans l'abondance et la biomasse de morue dans les strates de moins de 92 m de profondeur, estimées lors des relevés de navire de recherche, étaient significativement corrélées avec les températures de fond pour ces profondeurs.

1. Introduction

The general circulation in the 3P region consists of modified Labrador Current Water, the inshore branch of which flows through the Avalon Channel, and around Cape Race. This branch then divides into two parts, one flowing to the west around the north of St. Pierre Bank, and the other flows to the south between Green Bank and Whale Bank. Additionally, part of the offshore branch of the Labrador Current flows around the tail of the Grand Bank, westward along the continental slope (where it may interact with the Gulf Stream and slope waters), to the Laurentian Channel and into the Gulf of St. Lawrence (Fig. 1a).

Since the early 1970s, the ocean environment in the Northwest Atlantic has been dominated by near-decadal oscillations with cold periods in the early 1970s, mid-1980s and early 1990s and a general warming trend towards the mid-to-late 1990s. During the cold periods, colder-than-normal winter air temperatures prevailed over the Northwest Atlantic resulting in increased winter and spring ice cover and a colder and fresher-than-normal water mass overlying most of the continental shelf in Atlantic Canada (Colbourne et al. 1994; Drinkwater 1996). These conditions generally correspond to periods of positive winter North Atlantic Oscillation (NAO) index anomalies. The extent to which events influences the 3P region are documented by several studies (Hutchings and Myers 1994; Moguedet and Mahe 1991; Battaglia and Poulard 1987; Forest and Poulard 1981; Colbourne 1994, 1996, 1999, 2000, 2001, 2002 and 2003).

This report summarises oceanographic conditions in NAFO Division 3P up to the spring of 2003 and represents the seventh such review of winter/spring oceanographic conditions in support of the annual cod assessments for this region. The base period used to compute anomalies up to 2000 was defined as the 30-year time period from 1961-1990, in accordance with the convention of the World Meteorological Organization and recommendations from the North Atlantic Fisheries Organization's (NAFO) Scientific Council. Beginning in 2001 the base period used for the computation of anomalies has been advanced to 1971-2000. There are however, insufficient salinity data available in this time period to produce meaningful averages. Therefore the base period for salinity anomalies encompassed all available data from the mid-1920s to 2002.

Assessments of the cod stock in this region have indicated a steady decline in biomass (SPA estimates) from the peak in 1985 to a minimum in 1992 followed by an increase during 1993-1997 after the implementation of a fishing moratorium. Recruitment also experienced a general decline since the early 1980s remaining at historical low values during most of the 1990s with a slight increase during 1997-1999 (Brattey et al. 2002). In this report, we present an overview of oceanographic conditions during 2002 and 2003 and provide an update to Colbourne and Murphy (2002), where a review of recent trends in the distribution and abundance of cod in relation to their thermal habitat was presented.

2. Data and Methods

Oceanographic data for NAFO Division 3P are available from archives at the Marine Environmental Data Service (MEDS) in Ottawa and from a working database maintained at the Northwest Atlantic Fisheries Center (NAFC) in St. John's NL. The bulk of these data are temperatures collected during the Canadian groundfish assessment surveys of February, March and

April since 1973. The station positions where oceanographic measurements were available for the 2003 multi-species survey are shown in Fig. 1b. Since the winter of 1990, water temperatures and salinity on these surveys have been measured, for the most part, using a trawl-mounted Seabird 19 CTD. Prior to that, XBTs were the primary instrument. Data from the net-mounted CTDs are not field calibrated, but are checked periodically and factory calibrated when necessary maintaining an accuracy of 0.005°C in temperature and 0.005 in salinity. The XBTs are accurate to within 0.1°C. In addition to these data, all available historical data in the period 1971-2000 were used to establish the long-term means.

Vertical cross-sections of the temperature and salinity fields and their anomalies for April 2002 and 2003 were constructed by projecting the positions of all observations in corridor A (Fig. 1b) along a straight line with their offshore distances calculated from the shoreline in Sub-division 3Pn. The cross-section start near Rose Blanche on the south coast of Newfoundland, then follow a southeasterly direction crossing Burgeo Bank, Hermitage Channel, and St. Pierre Bank, terminating near the edge of the continental shelf on the southwestern Grand Bank.

All available oceanographic data were gridded for the winter-spring period of each year at a spatial resolution of approximately 100 km^2 or approximately 0.1° latitude by 0.1° longitude. The mean bottom temperature for each grid element was calculated and combined with the grid area to produce a time series of the spatially averaged bottom temperature and the total bottom area covered by water in selected temperature ranges. Bottom temperature and salinity maps and their anomalies for the spring of 2002 and 2003 were constructed by contouring the near bottom temperature and salinity values, rejecting ones for which the cast depths were not within 10% of the actual water depth. Some temporal biasing may exist in the T/S fields represented by these maps, particularly in shallow regions, given the large area and wide time interval (up to one month) over which the data were collected. A time-series of the gridded mean values were computed from 1970 to 2003 for temperature and from 1990 to 2003 for salinity.

Finally, a time-series of annual near-surface and near-bottom temperature anomalies were constructed from all available data throughout the year corresponding to area B of Fig. 1b, mainly St. Pierre Bank. The 1971-2000 data set from this area was sorted by month to determine monthly means. The seasonal cycle was then removed from each observation by subtracting the monthly mean to determine anomalies. Unlike the time series of anomalies from fixed points (e.g. Station 27), these anomalies are based on data collected over larger geographical areas and therefore may exhibit variability due to spatial differences in the monthly estimates. In addition, the annual values may be based on only a few monthly estimates for the year. Therefore, caution should be used when interpreting short time scale features of these series, however the long-term trends generally show real features.

The number of cod of all ages per set is displayed as expanding symbols together with the temperature contours for selected surveys, with an update for 2002 and 2003. The survey catch data from 1983 to the spring of 1995, which were collected using an Engel 145 bottom trawl, were converted to equivalent Campelen trawl units based on the results of comparative fishing studies. Inter-annual variations in the thermal habitat and its effects on cod are then considered by examining the mean temperature fields in relation to the RV estimates of biomass and abundance.

3. Physical Oceanography

3.1 Temperature Section

Vertical cross-sections of the temperature and temperature anomaly fields for April of 2002 and 2003 based on the multi-species survey data within Box A (Fig. 1b) are displayed Fig. 2. No attempts were made to adjust this average for possible temporal or spatial biasing arising from variations either in the number of observations within the time interval or within the area. The average upper layer temperature for April from near shore at Rose Blanche on the south coast of Newfoundland over Burgeo Bank and Hermitage Channel is about 1°C. Over St. Pierre Bank temperatures range from 1°C near the bottom to 2°C near the surface and from 1°-2°C beyond the shelf edge in the upper 100-m of the water column. In the deeper water of Burgeo and Hermitage Channels and on the continental slope temperatures are highly variable and generally range from 2°C at approximately 125-150 m depth to 5° - 7°C in the deepest water. At the edge of the continental shelf on southeastern St. Pierre Bank, the temperature field is marked by a strong gradient separating the warmer slope water from the Newfoundland Shelf water that is advected into the region by the inshore branch of the Labrador Current. In this region water temperatures increases from about 1°C at about 100-m depth, to between 5° to 6°C at about 175-m depth, an average vertical temperature gradient of 1°C per 15-m depth change (Colbourne 2000).

During April of 2002, upper layer (0-75 m) temperatures ranged from 0°-0.5°C near the coast and over Burgeo Channel and Bank and from 0.5° to 1°C over St. Pierre Bank (Fig. 2). These values were generally below normal, by up to 0.5°C in 2002 over most of the upper water column. During April 2003, upper layer temperatures decreased significantly compared to 2002 values by over 1°C over most areas. In 2003 the area with negative temperature anomalies increased over 2002, with values dipping as low as –1.5° to 2°C below normal over most areas. In the deeper waters (>180 m) of Burgeo and Hermitage Channels and the southeastern slopes temperatures were in the range of 3° to 6°C, which were generally above normal in 2002 and below normal in 2003. In general, spring temperatures along this section over most of the water column during 2001-2003 were below normal, reversing the warm trend of 1998-2000.

3.2 Bottom Temperatures

The average bottom temperatures for April ranges from 5°C in the Laurentian, Burgeo and Hermitage Channels to about 3° to 4°C on Rose Blanche and Burgeo Banks. On St. Pierre Bank bottom temperatures range from 0°C on the eastern side to 2° to 3°C on the western side. In general, bottom isotherms follow the bathymetry along the Laurentian Channel and the southwestern Grand Bank, decreasing from 2°C at 200-m depth to about 5°C below approximately 300-m depth (Colbourne 2000).

During the spring of 2003, bottom temperatures over St. Pierre Bank decreased significantly over 2002 values with <0°C water covering most of the Bank and regions to the east (Fig. 3). Consequently, below normal temperatures were more widespread during 2003 compared to 2002, covering most of the bottom areas in the 3P region with values as low as 1°C below normal (Fig. 3). During April 2002, bottom temperatures were above average over Burgeo and Rose Blanche Banks, while Hermitage Channel bottom temperatures were mostly below normal. During 2003, they were

below normal over all areas, except for Rose Blanche Bank. In general, the area of the bottom covered by below normal temperatures increased significantly during the spring of 2003, compared to 2002.

Annual values of the areal extent of the bottom covered with water in the temperature ranges of <0°C, 0°-1°C 1°-2°C 2°-3°C and >3°C are displayed in Fig. 4. Note the large increase in the percentage area of the bottom covered by <0°C water in 1985 that persisted well into the mid-1990s, with the exception of 1988. The percentage area covered by <0°C water during the spring of 1998 decreased to pre-1985 levels and to less than 10% during 2000, but increased to over 25% during 2001 and 2002 and to near 40% in 2003. The bottom area covered with water between 0-1°C, except for 1979 and 1988, has remained below 20%. The bottom area with temperatures >1°C before 1985 was approximately 70-80% and from 1984 to 1995 had been nearly constant between 50-70%. Since 1995, except for 1997 this area has been increasing and approached pre-1985 values during 1999 and 2000. During the spring of 2001 however, this area decreased to between 50-60%, increased slightly in 2002 and decreased again in 2003. During the spring of 1999 and 2000 <0°C water had essentially disappeared from the St. Pierre Bank, but reappeared during 2001, reaching near 30% coverage in 2002 and over 90% coverage in 2003. The area of near-bottom water on the banks with temperatures >1°C increased from about 50% in 1998 to near 85% during 2000, the first significant amount since 1984 (Colbourne 2001).

The average bottom temperature of the surveyed area in Division 3P ranged between 2° - 4°C from 1970 to 1984 and decreased to between 2° - 2.5°C from 1985 to 1997. During 1999 and 2000 the average near-bottom temperature increased to over 3°C but decreased to near 2.5°C in 2001 and to 2°C by 2003 (Fig. 4, bottom panel). On the banks, in water depths generally <100-m, the average temperature from 1970 to 1985 ranged between approximately 0.5° to 1°C. It then decreased significantly during 1985 and has slowly recovered to about 1°C by 1998, 1.6°C during 1999 and to 1.7°C during 2000. During the spring of 2001 and 2002, the spatially averaged bottom temperature on the banks decreased to near 0°C and during 2003, it decreased further to –0.7°C, the lowest value since 1985.

3.3 Long-Term Trends

Annual near-surface and 75-m depth temperature anomalies from 1950 to 2003 on St. Pierre Bank bounded by the 100-m isobath (Fig. 1b) are shown in Fig. 5. The time series is characterised by large inter-annual variations with amplitudes ranging from ±1.5°C from normal. The long-term trend shows amplitudes generally less than ±1°C with periods between 5 to 10 years. The cold periods of the mid-1970s and the mid-1980s in the upper water column are coincident with severe meteorological and sea-ice conditions in the Northwest Atlantic and generally colder and fresher than normal waters over most of the Canadian Continental Shelf. During the cold period beginning around 1984 temperatures decreased significantly by over 1°C in some years. This below normal trend continued until the mid-1990s, however since then temperatures began to warm and from 1997 to 2000, they were above normal. During 2001 temperatures decreased significantly over 2000 values at both the surface and at 75-m depth, reaching values typical of the early 1990s. During 2002 temperatures increased slightly over 2001 values at the surface to near normal values but remained below normal at 75 m depth and during 2003, they decreased significantly to 0.5°C below normal at the surface and to 0.7°C below normal at 75 m depth.

3.4 Salinity Section

Vertical cross-sections of salinity and salinity anomalies for April of 2002 and 2003 are shown in Fig. 6. In order to obtain enough data to construct realistic anomaly fields the complete data set dating back to the mid-1920s was used. No attempts were made to adjust the average for possible temporal or spatial biasing arising from variations either in the number of observations within the time interval or within the area. An examination of the data indicates that the observations are well distributed geographically across the complete section, however temporally most of the data have been collected since the early 1990s after the implementation of the trawl-mounted CTD system.

The average upper layer salinity for April from near-shore at Rose Blanche on the south coast of Newfoundland and over Burgeo Bank and Hermitage Channel ranges from about 32 to 32.2. Over St. Pierre Bank, salinities generally range from 32.5 near bottom, to a low of 32.1 near the surface. Along the shelf edge, in the upper 100-m of the water column, there is a strong density front separating the warmer slope water from the Labrador Current shelf water over St. Pierre Bank, in this region salinities generally increase from 32.3 to over 34. In the deeper waters of Burgeo and Hermitage Channels and on the continental slope regions salinities normally increase from 33 at approximately 130-m to 34.5 near bottom (Colbourne 2000).

During April of 2002 (Fig. 6 upper panels) near-surface salinities ranged from <32 near the coast and over Burgeo Channel and Bank and <32.5 over St. Pierre Bank, these values were generally near-normal to slightly fresher than normal over St. Pierre Bank. Salinities below 150-m depth ranged from 33 to >34.5, which for the most part, were near-normal except on the southeast slopes where they were generally fresher than normal in the depth range of 100-200 m. Upper layer salinities during April 2003 increased over 2002 values, particularly on St. Pierre Bank, to slightly saltier-than-normal. In deeper waters (>100 m) salinities during the spring of 2003 ranged from near normal to slightly fresher-than-normal (Fig. 6 bottom panels).

3.5 Bottom Salinity

The average bottom salinities for the winter-spring period ranges from 34 to 34.5 in the Laurentian, Burgeo and Hermitage Channels, from about 33 to 33.5 on Burgeo Bank and from about 32.25 to 33 on most of St. Pierre Bank. On the slopes of St. Pierre Bank (100-300 m), salinities generally range on average from 33 to 34.5 (Colbourne 2000). During April of 2002 bottom salinities were generally above average (by 0.5) over most of western regions and generally below normal over most of St. Pierre Bank, Hermitage Channel and regions to the east (Fig. 7 left panels). During the spring of 2003 near bottom salinities over St. Pierre Bank and regions to the east increased to between 32.5-33, these were generally saltier-than-normal. Along the slopes of the Laurentian Channel, salinities were lower than normal in 2003 (Fig.7 right panels).

Areal indices based on selected salinity ranges were computed using the same method as was used for temperature, these are displayed in Fig 8 for the ranges of ≤32.25, 32.25-32.5, 32.5-32.75 and >32.75. The areal index was only calculated for the banks with water depths ≤100-m, below that there does not appear to be any significant trend in the salinity data. The analysis is based on salinity data collected during the multi-species surveys from trawl-mounted CTD for the years 1990-2003.

The areal extent of bottom water with salinities ≤32.5 was near constant from 1990-1997 at about 80-90%. During 1998 it decreased to about 35% and increased to over 90% during 2000 but decreased to near 0% in 2001 when conditions were much saltier-than-normal. During April of 2002 it increased again to near 80% but decreased to 50% in 2003. The areal extent of bottom water on the banks with salinities >32.5 ranged <10-25% from 1990 to 1997 but increased to about 65% in 1998, which decreased to <10% during the spring of 2000. During the spring of 2001 almost all of St Pierre Bank was covered by water with salinities >32.5 (Fig. 8 top panel), while 2002 and 2003 the areal coverage ranged from 15-50%.

The average bottom salinity of the surveyed area in Division 3P (Fig. 8, bottom panel) ranged between 33.3 to 33.45 from 1990 to 1996. From 1997 to 1999 the average salinity increased to 33.56, but decreased again in 2000 to 33.38. During 2001 average salinities were similar to 1999 values but decreased slightly in 2002 and remained about the same in 2003. On the banks in water depths <100-m the average bottom salinity was near constant at about 32.35 from 1990 to 1997 but then increased to 32.6 in 1998, which decreased to 32.48 in 1999. During the spring of 2000, salinities on the banks decreased to 32.14 the lowest in the 13 record. During April of 2001 however, salinities increased significantly over 2000 and were similar to values observed during 1998. During 2003 salinities increased slightly over 2002 values to around 32.5. In general, since 1998 average salinities in water depths <100 m have been highly variable compared to pre-1998 levels.

4. Atlantic Cod and the physical environment

The near-bottom habitat in the 3P region consists of two distinct oceanographic regimes. The one influenced by cold and relatively fresh water advected from the eastern Newfoundland Shelf by the inshore branch of the Labrador Current includes much of St. Pierre Bank and regions to the east. In this area temperatures generally range from 0°-2°C but are often <0°C in many years. The other regime includes the deeper portions of the Laurentian and Hermitage Channels and areas to the west of St. Pierre Bank. This area appears to be influenced mostly by warmer slope water from the south. Consequently, this region experiences high variability with temperatures ranging from 3°-6°C. A significant shift in the thermal habitat influenced by the Labrador Current took place during the mid-1980s with a significant increase in the area of the bottom covered with <0°C water. Beginning in 1996 the area of <0°C water on the banks decreased significantly, reaching very low values in 1998 and essentially disappearance during the warm years of 1999 and 2000.

Spring bottom temperature maps together with the number of fish caught per set for Division 3P are shown in Fig. 9 for 1993 a cold year, 2000 a warm year and for 2002 and 2003, which were also cold years. The most evident pattern in the number of cod caught per set (displayed as expanding symbols on the temperature fields) is the high number of sets with zero catches for the cold years of 1993, 2002 and 2003. This pattern persisted from 1985 to 1998 when most of St. Pierre Bank and regions east of the Bank were covered by bottom water with temperatures <0°C. During 1999 and 2000 larger catches became more wide spread over St. Pierre Bank and surrounding area as cold (<0°C) water disappeared from the area (Colbourne and Murphy 2002). During 2001 to 2003 however, cold water returned to the area and the number of fishing sets with zero catches also

increased. During all surveys most of the larger catches occurred in the warmer (2°-3°C) waters along the slopes of the banks and in the deep channels to the west of St. Pierre Bank.

To investigate possible temperature preferences by cod in this region, cumulative distributions of temperature and catch weighted (in terms of numbers and weight) cumulative distribution of temperature for various periods are displayed in Fig. 10. The temperature distributions have been weighted annually by sampling intensity within each stratum and by strata area. The cumulative frequency distribution of temperature shows the temperature available to cod historically during the spring period in Division 3P. The cod number and weight temperature distributions show the distribution of catches in relation to the ambient temperature. The results indicate that on average (1972-2001) cod are associated with the warmer portion of the available temperature range with a slightly warmer preference based on weight than numbers. This may imply a greater degree of habitat selection by larger cod. Approximately 20% of the cod by number are associated with <0°C water, while approximately 50% are associated with water >3°C and up to 25% associated with temperatures >5°C. The temperature distribution indicate that about 40% of the surveyed habitat is normally (1972-2001) covered by water with temperatures <0°C. During the warm periods of 1974-1984 and 1998-2000 the distribution of catches nearly coincide with the distribution of available temperature, but during the cold period of 1985-1995, the distributions indicate that the fish may avoid the colder portions of the habitat. The distributions during the past 3 years (2001-2003) are very similar to those of the cold period 1985-1995 (Fig. 10).

Inter-annual variations in the spatially averaged bottom temperature of the surveyed area in Division 3P are plotted in Fig. 11 and 12 together with the RV estimates of abundance and biomass for the years 1983 to 2003. Apart from the general decrease in both abundance and bottom temperature from the mid-1980s to the early 1990s and for the most recent years, there is no significant correlation between bottom temperatures and the abundance and biomass of cod (Fig. 11). On the banks however, and in water depths generally <100 m, the average bottom temperature is significantly correlated with the RV abundance ($r=0.59$, $p<0.05$) and biomass ($r=0.63$, $p<0.05$) corresponding to strata with water depths <92 m (Fig. 12). In general, the cold bottom temperatures experienced during the winter and spring from the mid-1980s to the mid-1990s and during 2001 to 2003 correspond to low RV estimates of abundance and biomass.

The results presented suggest that cod tend to avoid the colder portions of the thermal habitat in this region and consequently change their spring distribution from one year to the next, depending on ocean climate conditions. This result is not without exception however (e.g. 1983 and 1987) and there may be other reasons for the observed changes in distribution. For example, the extreme variations in the catch rates on St. Pierre Bank, in particular, may be the result of a temperature dependent increase in catchability. It could also be related to other biological or environmental factors, such as increase in prey species or a shift to a more suitable environment for prey species. Variations in the catch rates in the warmer water of the most western regions of Subdivision 3Pn may be influenced by environmental conditions in the Gulf of St. Lawrence, either for cod or their prey, or both. Although the numbers of fish from the 1983-1995 surveys have been converted to equivalent Campelen trawl units there may be some residual effects remaining in the series, which may have contributed to some of the increase in the catches of smaller fish during 1996-2003. Variations in water temperature in

the area, particularly on St. Pierre Bank and the eastern areas of 3P may also influence spawning success and possibly improved survival and growth rates of cod.

5. Summary

Time series of temperature anomalies from NAFO Division 3P (particularly on St. Pierre Bank) show anomalous cold periods in the mid-1970s and from the mid-1980s to late 1990s. These conditions were similar to those observed along the east coast of Newfoundland and Labrador, except the latter cold period lasted longer on St. Pierre Bank than it did on the eastern Newfoundland Shelf. During the most recent cold period, which started around 1985, temperatures were up to 1°C below average over all depths and up to 2°C below the warmer temperatures of the late 1970s and early 1980s in the surface layers. Temperatures in deeper water off the banks during all years show significant variations, but remained relatively warm with values in the 3°-6°C range, compared to much colder values (often <0°C) on St. Pierre Bank. Beginning around 1996 temperatures on St. Pierre Bank started to moderate, decreased again during the spring of 1997, but returned to normal values during 1998. During 1999 and 2000 temperatures continued to increase reaching the highest values since the late 1970s in the surface layers. During the spring of 2001 and 2002 however, temperatures cooled significantly over the previous two years to values observed during the mid-1990s and to values observed during the mid-1980s by the spring of 2003. The areal extent of <0°C bottom water increased significantly from the mid-1980s to the mid-1990s but decreased to very low values during 1998-2000. During 2001 however, it increased again, returning to values observed during the mid-1990s, decreasing slightly again during 2002 only to increase to >40% in 2003, the highest in about 13 years. The areal extent of bottom water with temperatures >1°C increased to pre-1985 values during 1999-2000 but during the last three years it has decreased by about 25%.

On St. Pierre Bank bottom water with temperatures <0°C essentially disappeared during the warm years of 1999 and 2000. It has since increased to between 20-30% during 2001 and 2002 and to over 90% in the spring of 2003. The area of near-bottom water on the banks with temperatures >1°C was about 50% of the total area during 1998, the first significant amount since 1984. This subsequently increased to about 70% during 1999 and to 85% during 2000, but decreased to low values during the past 3 years.

The analysis presented here show significant variations in the water mass characteristics particularly on St. Pierre Bank during the past several years. From the mid-1980s up to 1997, a cold near constant salinity water mass influenced most of the upper 100-m of the water column. A change to much warmer and saltier conditions occurred during 1998 and 1999 and to fresher but still warm conditions during 2000. During 2001 salinities increased to above normal values, while temperatures generally decreased to below normal values as cold water returned to the region. Oceanographic observations during the spring of 2003 indicate a continuation of the decreasing trend in temperatures that began in 2001.

The dominant oceanographic signal potentially influencing cod habitat in this region is the volume of <0°C water advected into the region from the eastern Newfoundland Shelf by the inshore branch of the Labrador Current. The extent and temperature of this water mass that eventually makes its way onto St. Pierre Bank is governed by advection rates, vertical mixing by storms during the winter and spring and surface heat flux. The most evident trend in the numbers of cod caught

per set is the high number of zero catches in the cold (<0°C) waters on St. Pierre Bank and regions to the east f St. Pierre Bank mainly from 1985 to 1998 and from 2001 to 2003. During 1999 and 2000 larger catches became more wide spread over St. Pierre Bank region as the cold (<0°C) water disappeared from the area. In general, during all surveys most of the larger catches occurred in the warmer waters (2°-6°C) along the slopes and areas to the west of St. Pierre Bank. In addition, variations in the estimated abundance and biomass of cod in strata with water depths <92 m are significantly correlated with bottom temperatures for that depth range. However, there is no significant correlation between bottom temperatures and the abundance of cod for strata with water depths >100 m. Nevertheless, it appears that cod tend to avoid the colder portions of the thermal habitat in this region and consequently change their spring distribution from one year to the next, depending on ocean climate conditions.

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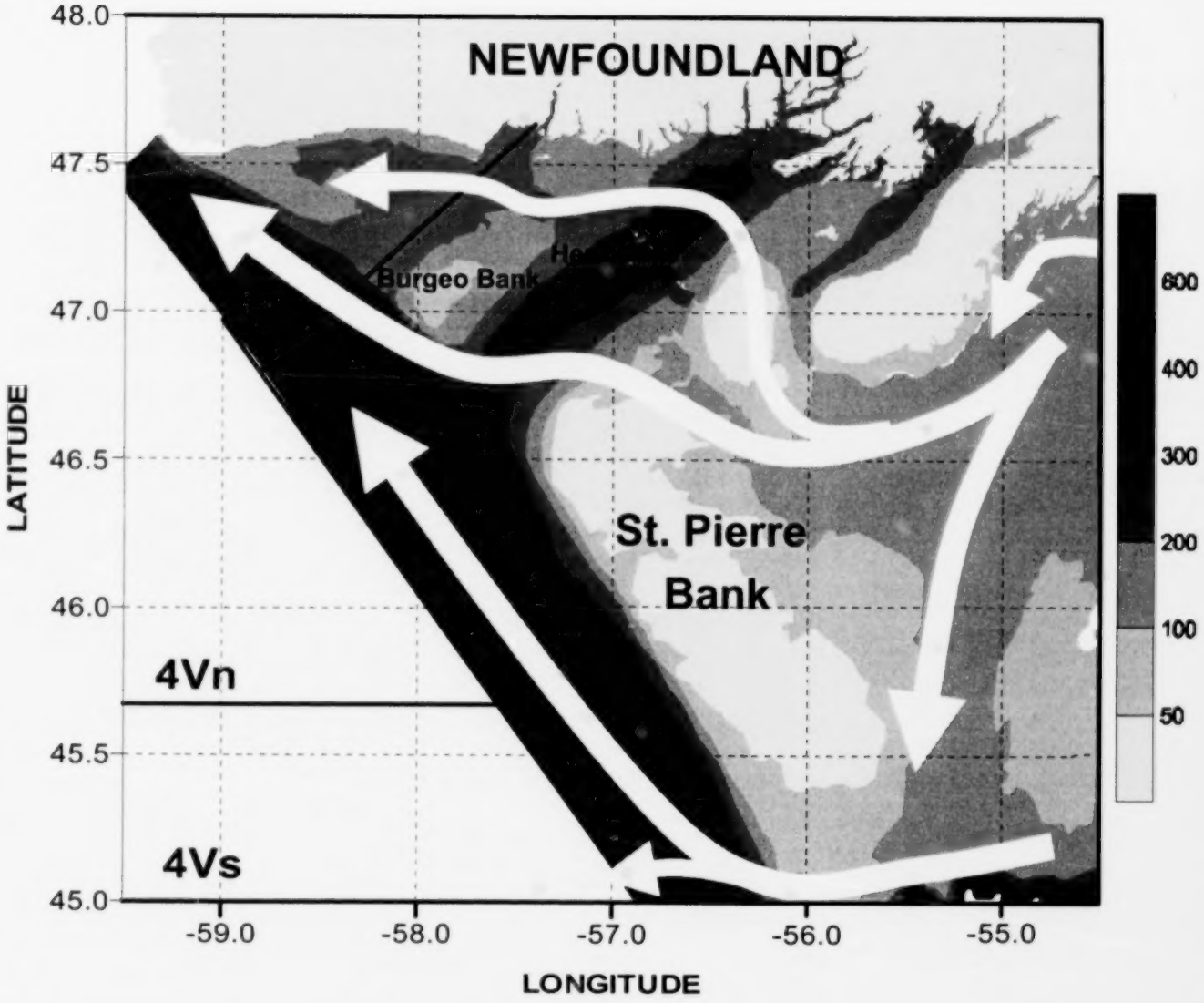


Fig. 1a. Location map showing the bathymetric features (in metres) and the general ocean circulation of NAFO Division 3P.

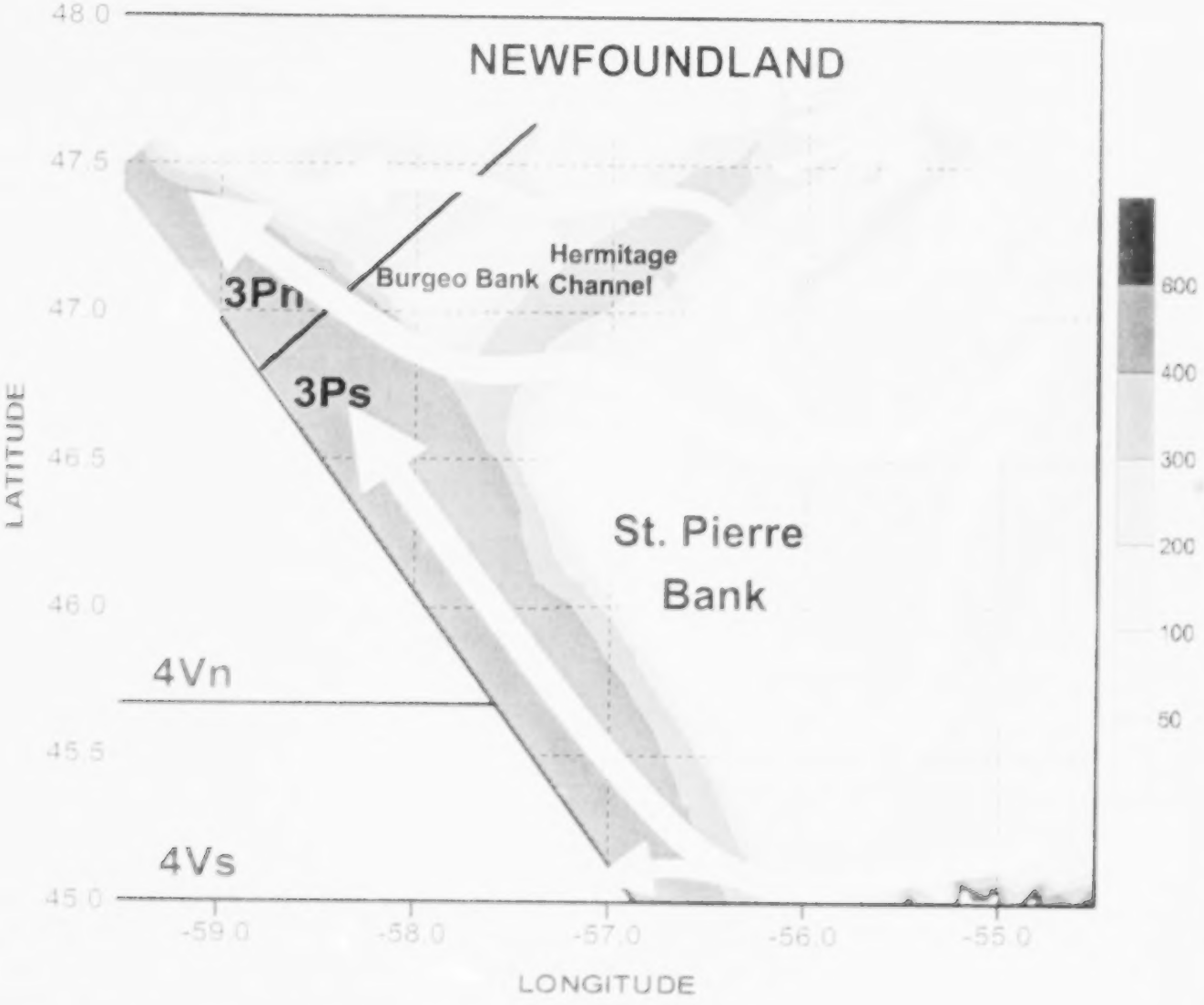


Fig. 1a Location map showing the bathymetric features (in metres) and the general ocean circulation of NAFO Division 3P

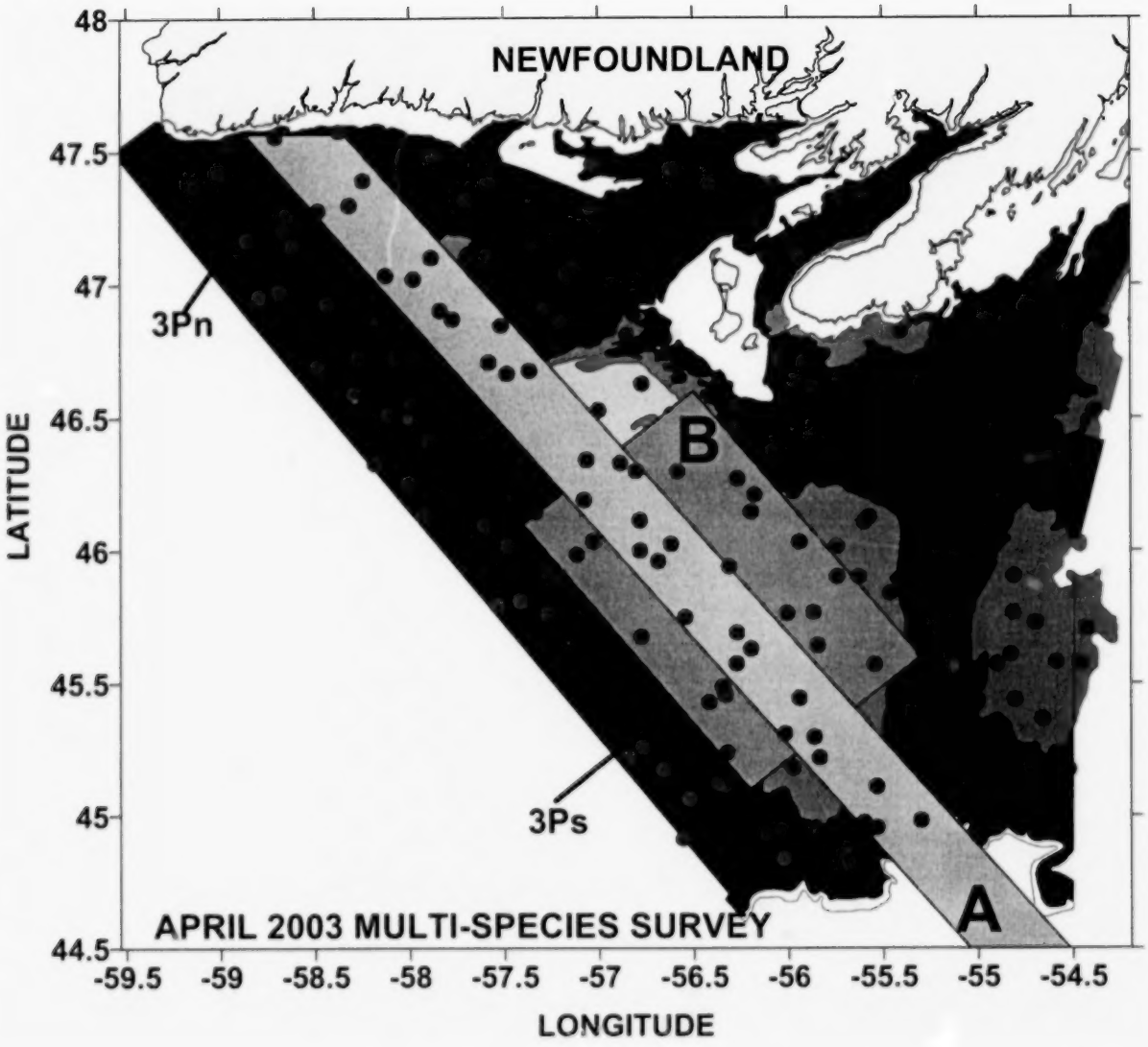


Fig. 1b. Location map showing NAFO Subdivisions 3Pn and 3Ps and the areas A and B from which cross-sections and time series of temperature and salinity were constructed. The set positions where oceanographic measurements were available for the 2003 spring multi-species survey are also shown as well as the strata boundaries.

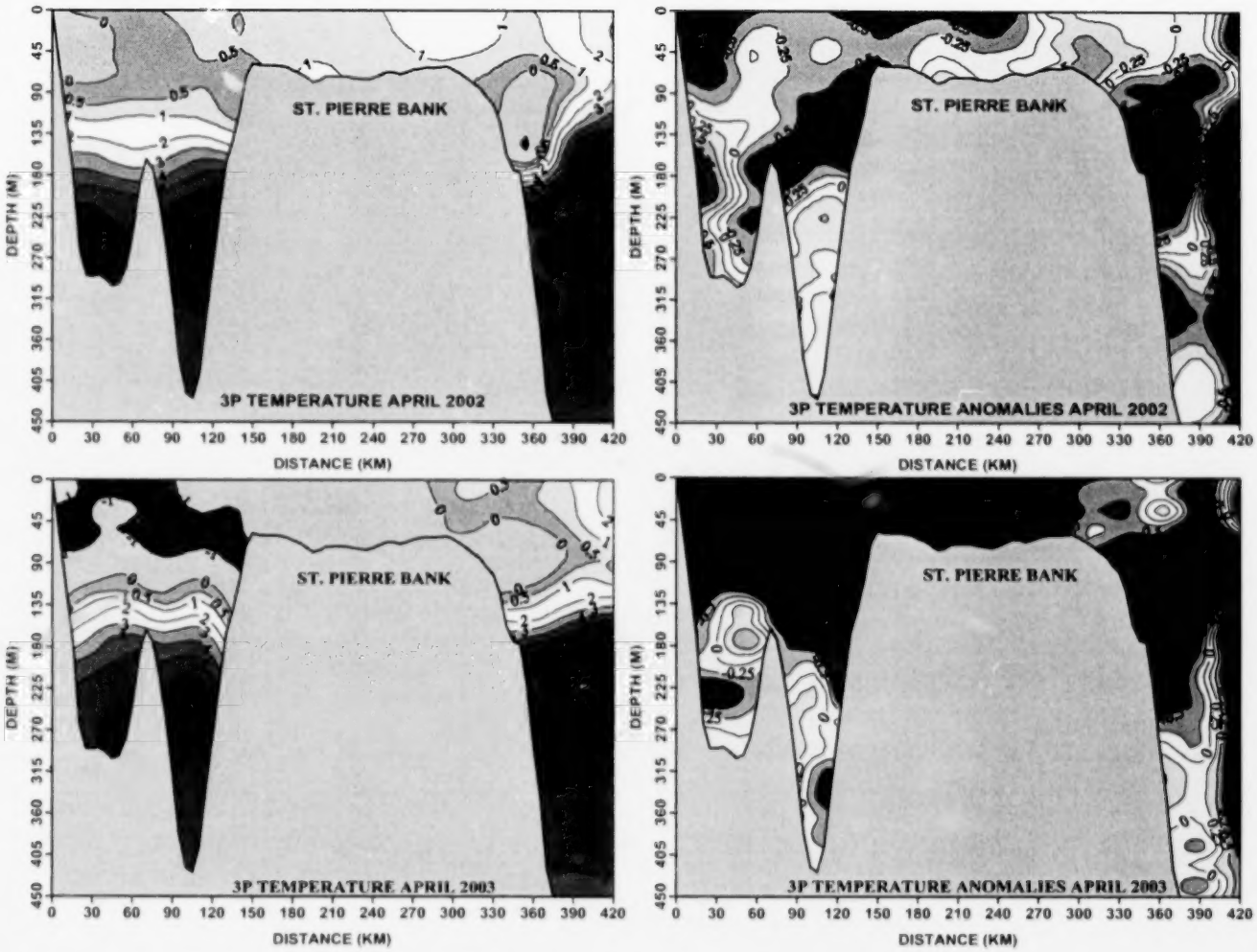
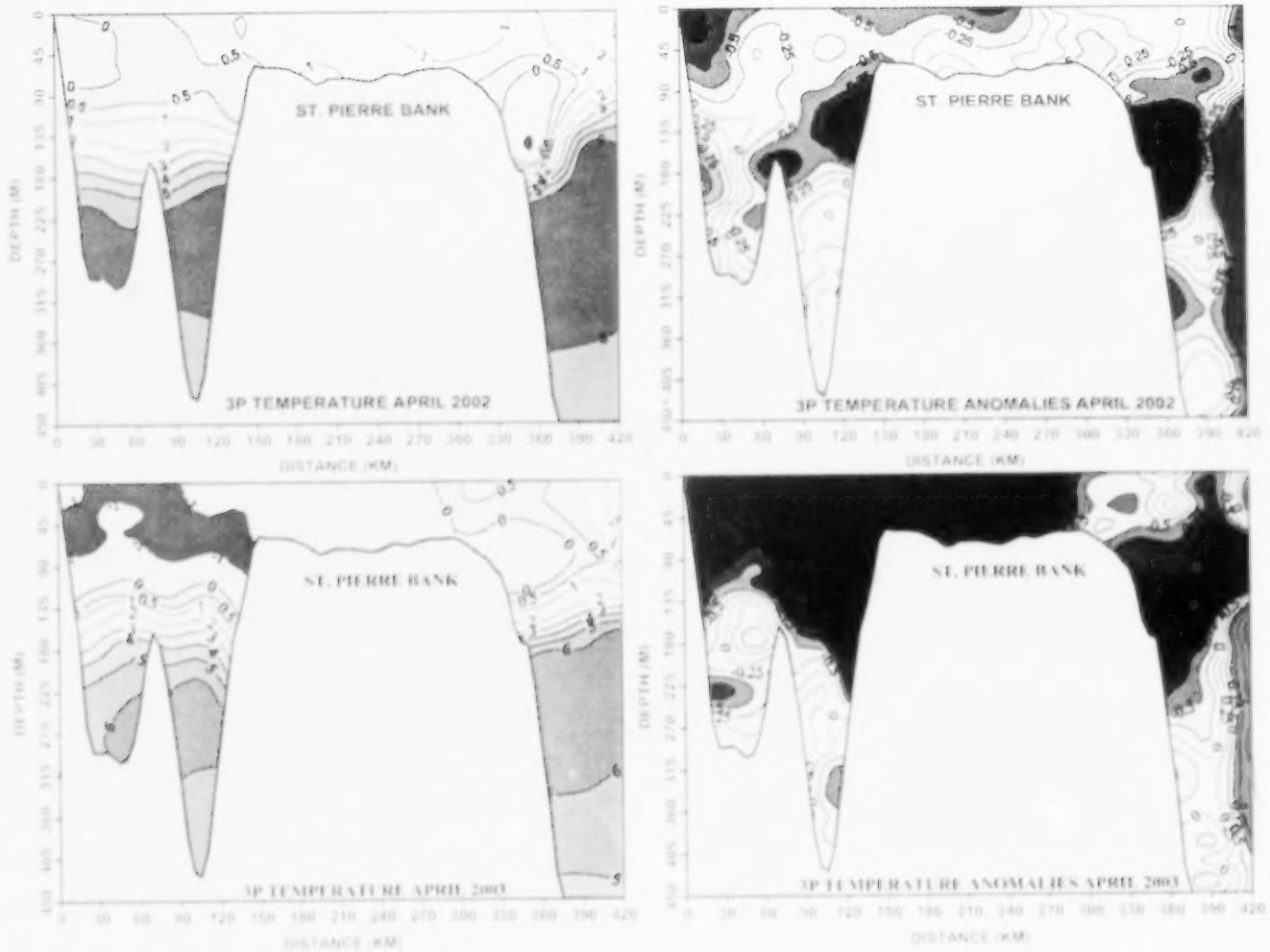


Fig. 2. The April 2002 and 2003 temperature and anomalies (in °C) along the section constructed from the data in Box A of Fig. 1b for NAFO Subdivisions 3Pn and 3Ps. The anomalies are referenced to the 1971-2000 average.



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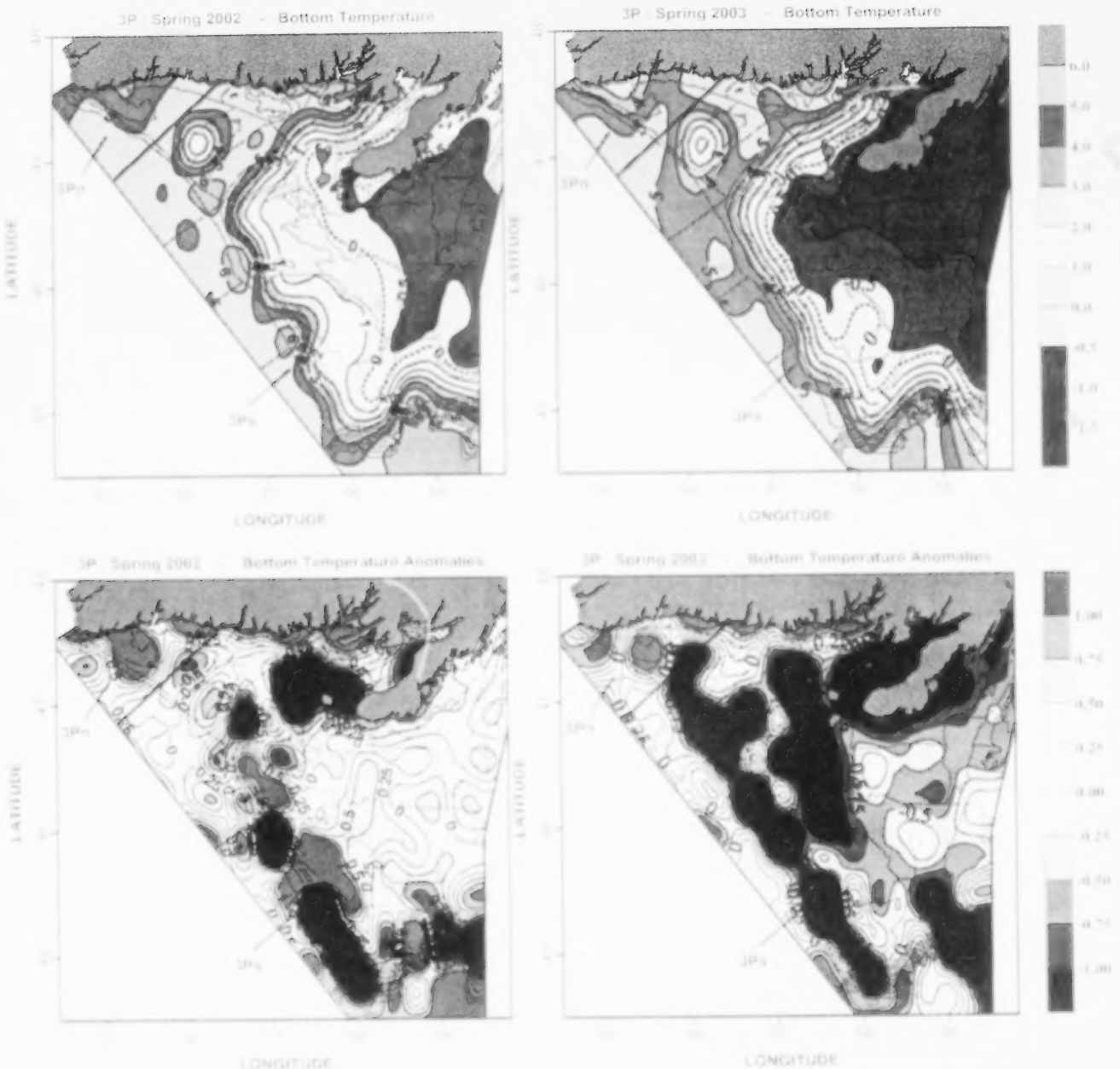


Fig. 3.3.1 The April 2002 and 2003 bottom temperature and anomalies (in °C) on NAFO Subdivisions 3Pn and 3Ps. The anomalies are referenced to the 1971-2000 averages.

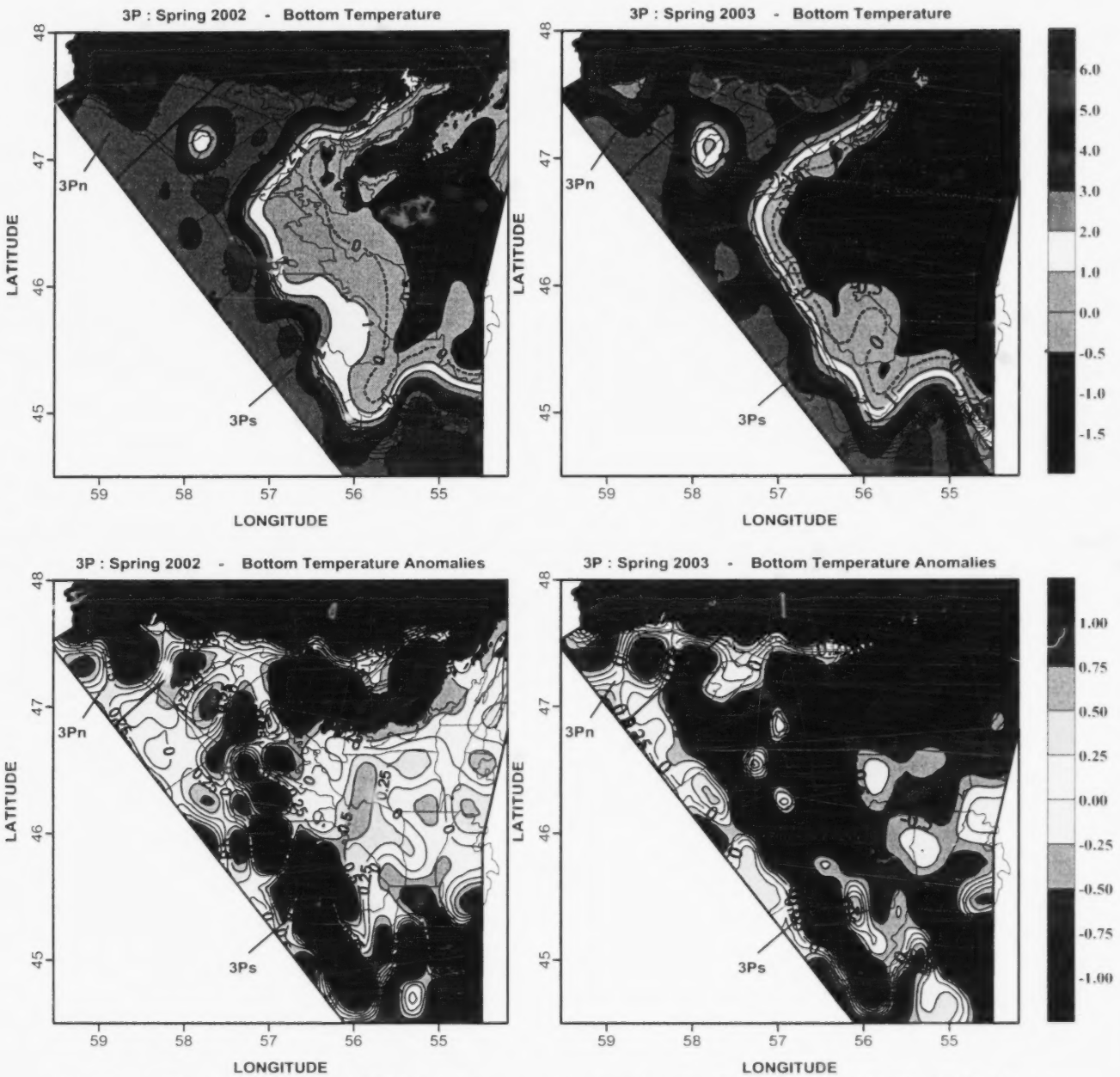


Fig. 3. The April 2002 and 2003 bottom temperature and anomalies (in °C) in NAFO Subdivisions 3Pn and 3Ps. The anomalies are referenced to the 1971-2000 average.

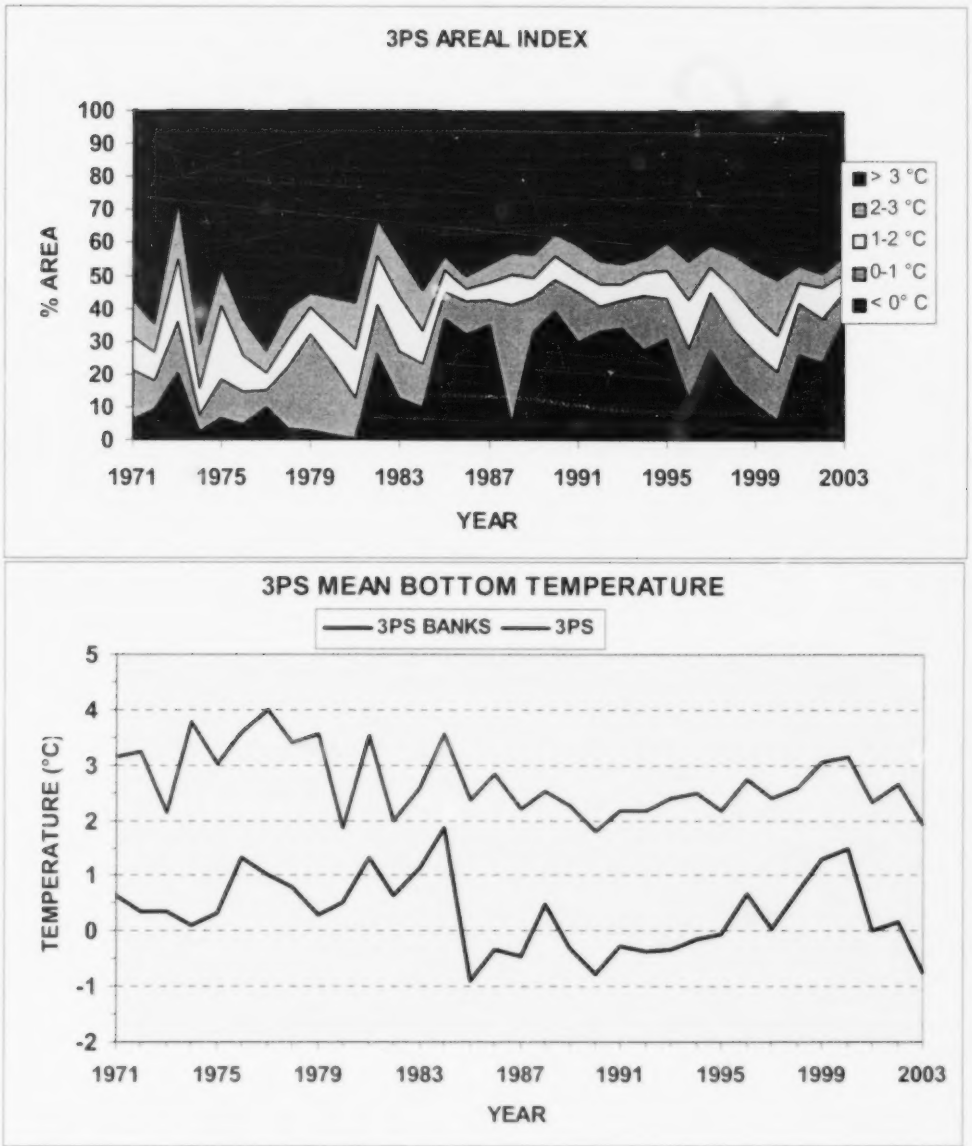


Fig.4. Time series of the percentage area of the bottom in NAFO Division 3P during the winter/spring covered by water with temperatures ≤0°C, 0°-1°C, 1°-2°C 2°-3°C and ≥3°C (top panel) and the mean bottom temperature (in °C) for all strata and for strata with water depths <100 m (bottom panel).

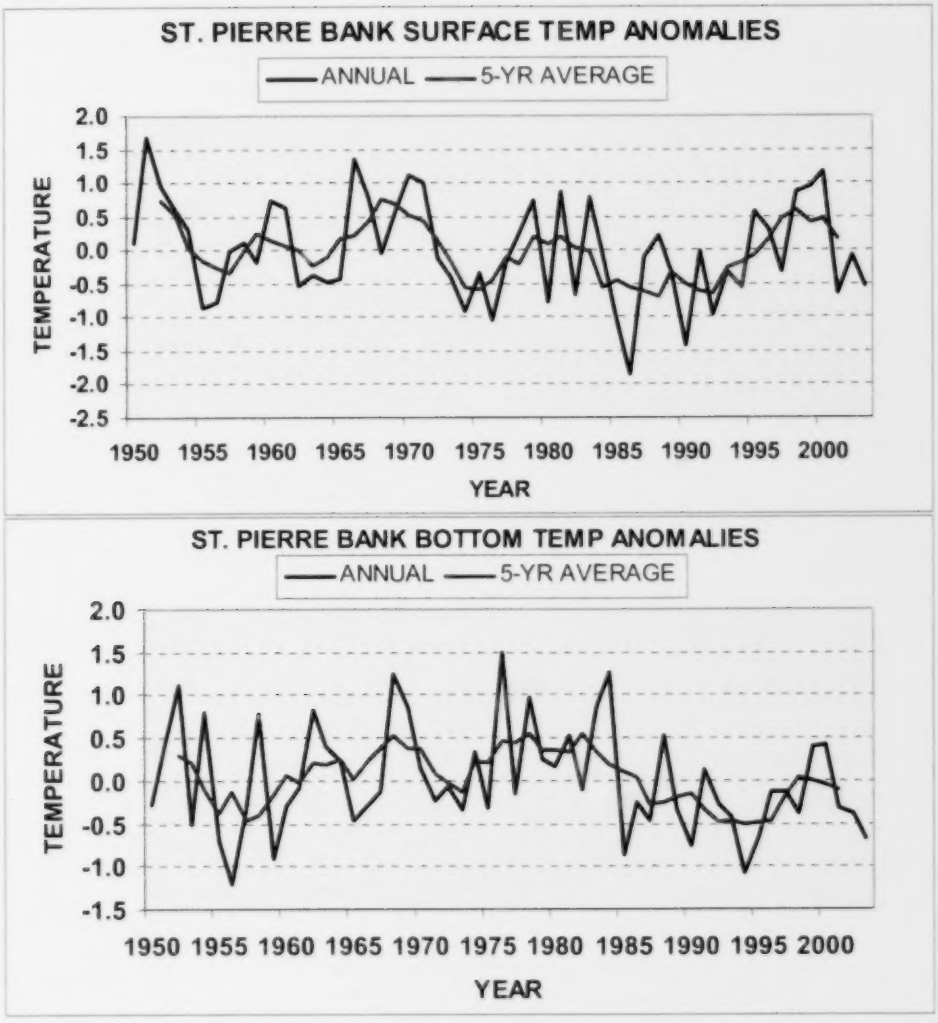


Fig. 5. Annual temperature anomaly time series (in °C) for the near-surface (5 m) and near-bottom (75 m) constructed from all historical data in Box B of Fig. 1b. The heavy solid line represents the 5-year running mean.

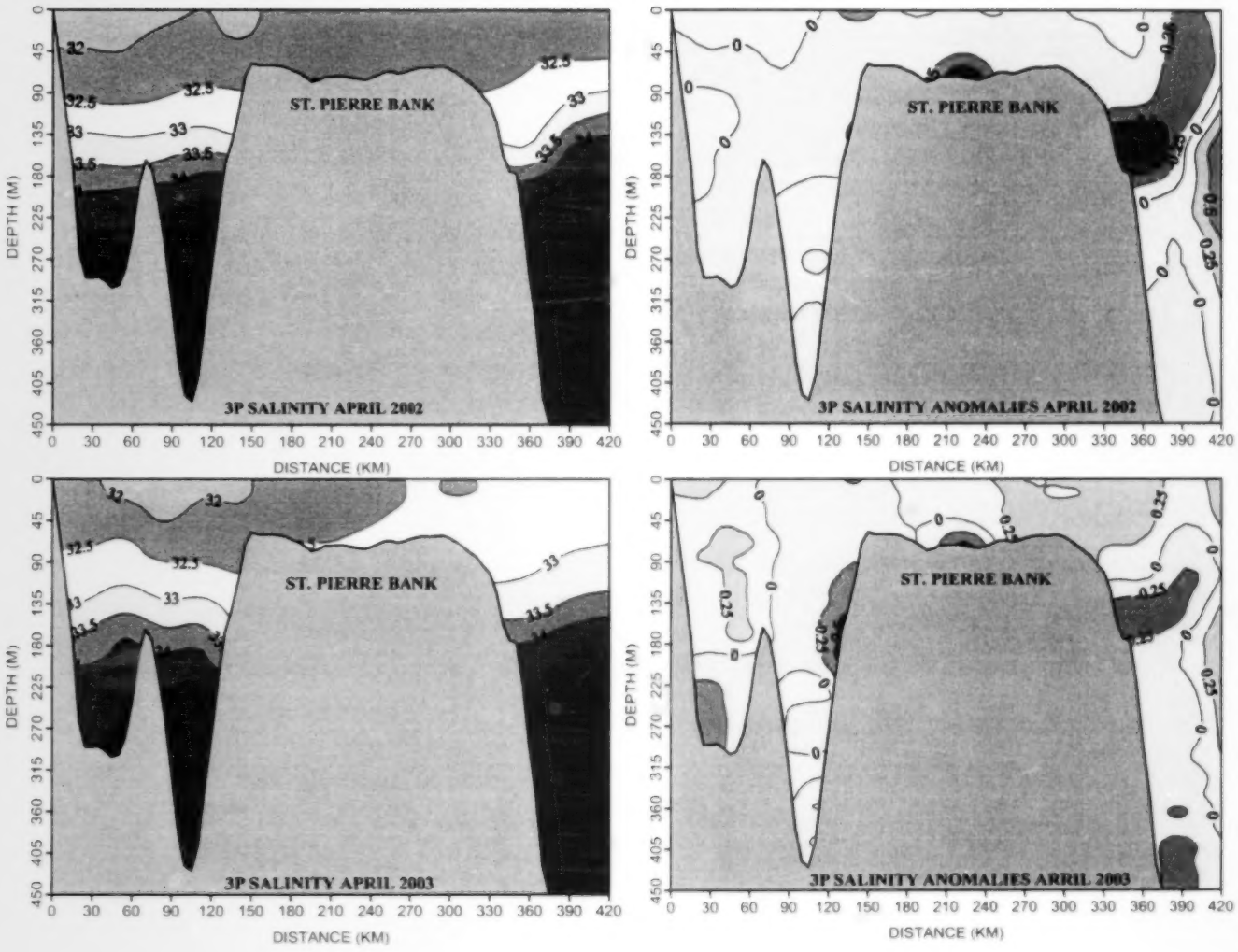
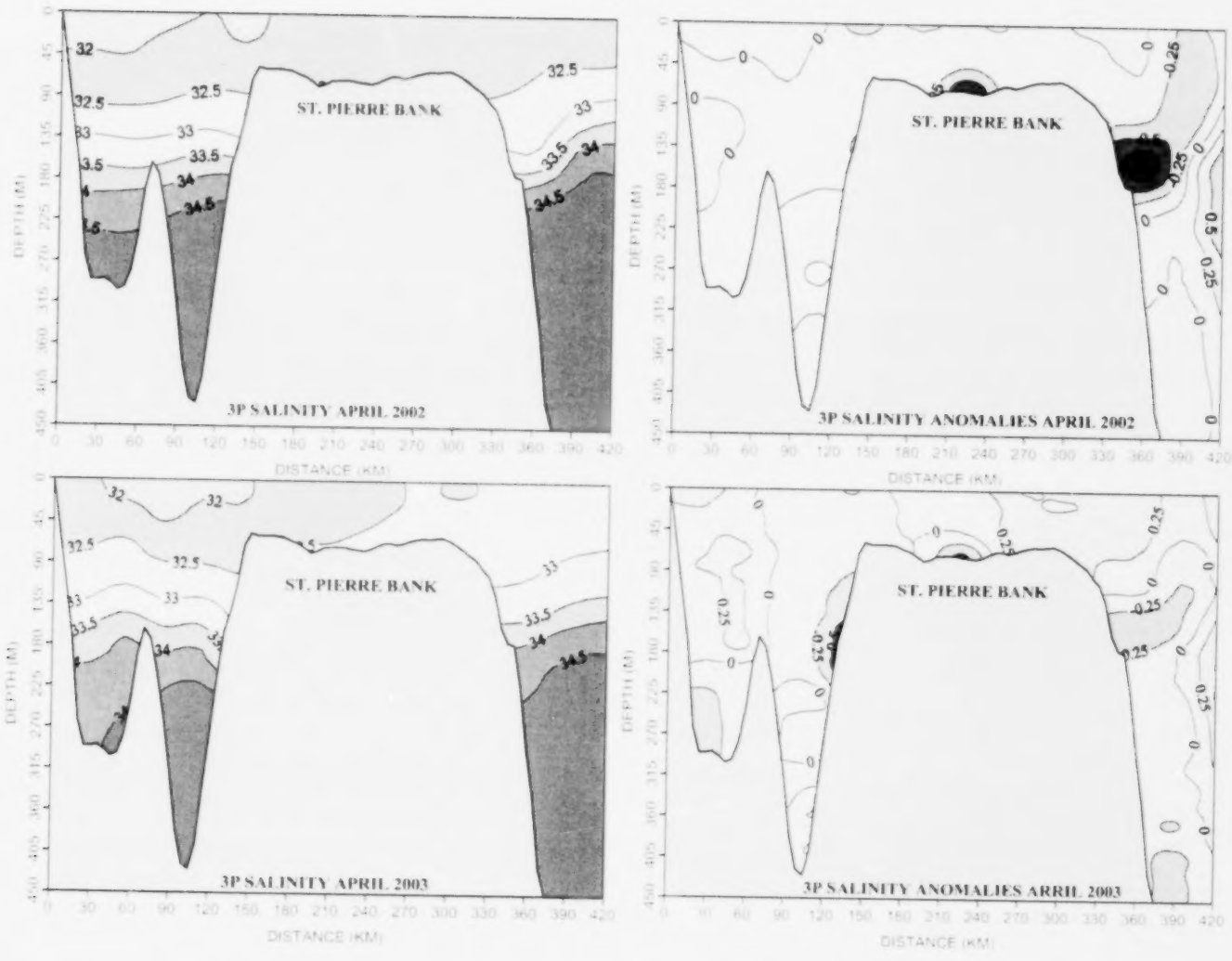


Fig. 6. The April 2002 and 2003 salinity and salinity anomalies along the section constructed from the data in Box A of Fig. 1b for NAFO Subdivisions 3Pn and 3Ps. The anomalies are referenced to the 1925 to 2000 average.



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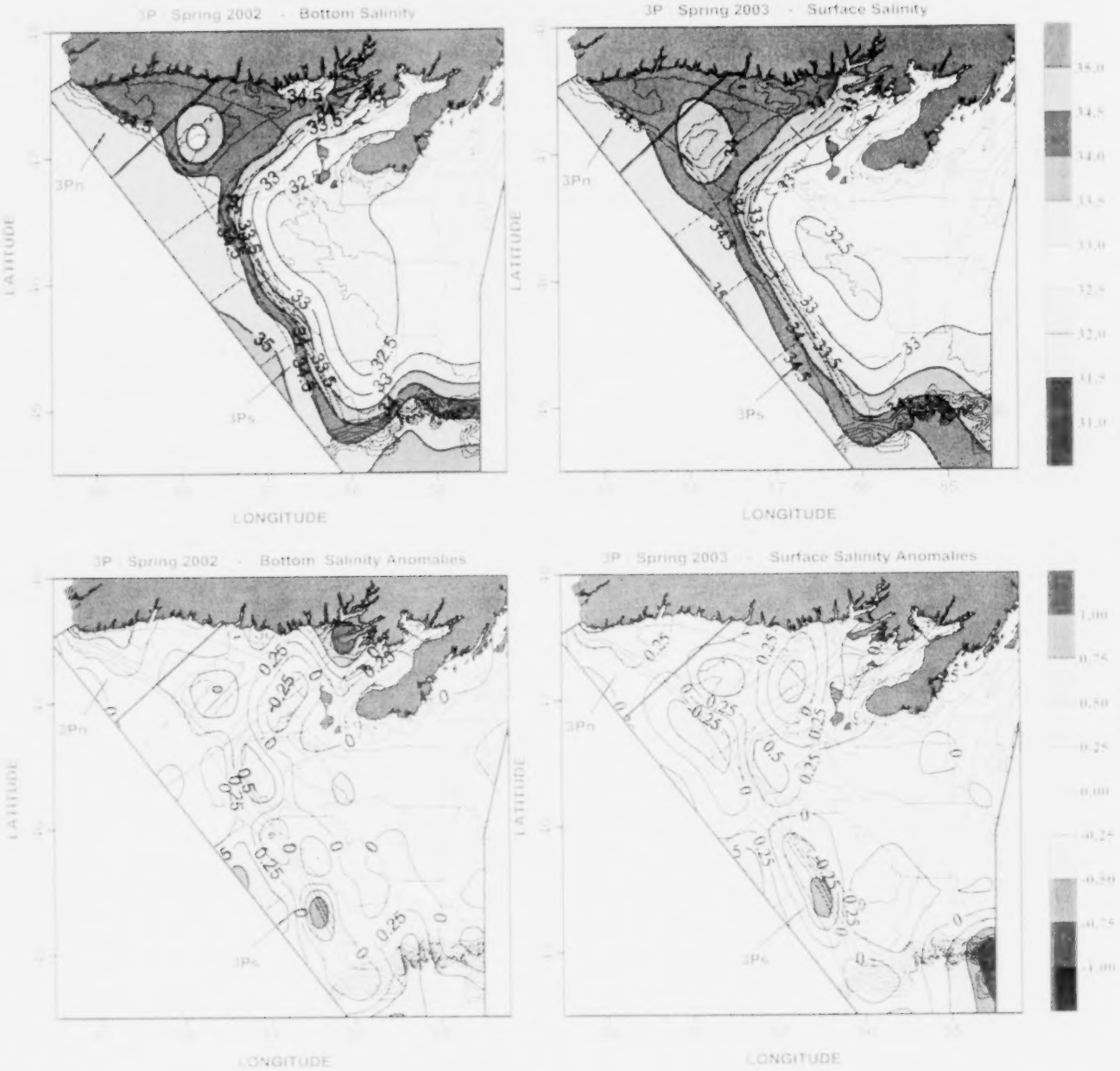


Fig. 7. The April 2002 and 2003 bottom salinity and salinity anomalies in NAFO Subdivisions 3Pn and 3Ps. The anomalies are referenced to the winter-spring 1925-2000 average.

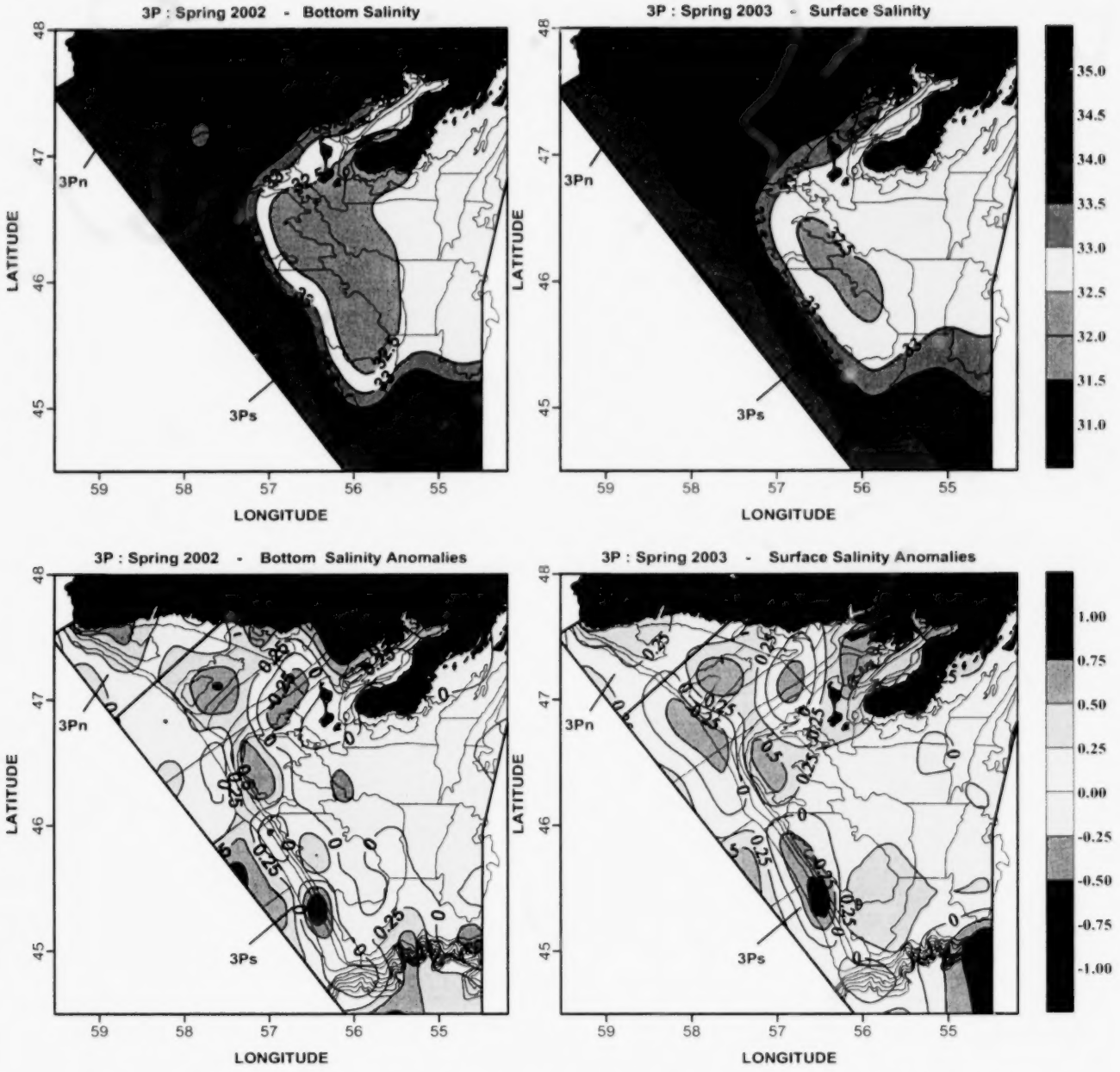


Fig. 7. The April 2002 and 2003 bottom salinity and salinity anomalies in NAFO Subdivisions 3Pn and 3Ps. The anomalies are referenced to the winter/spring 1925-2000 average.

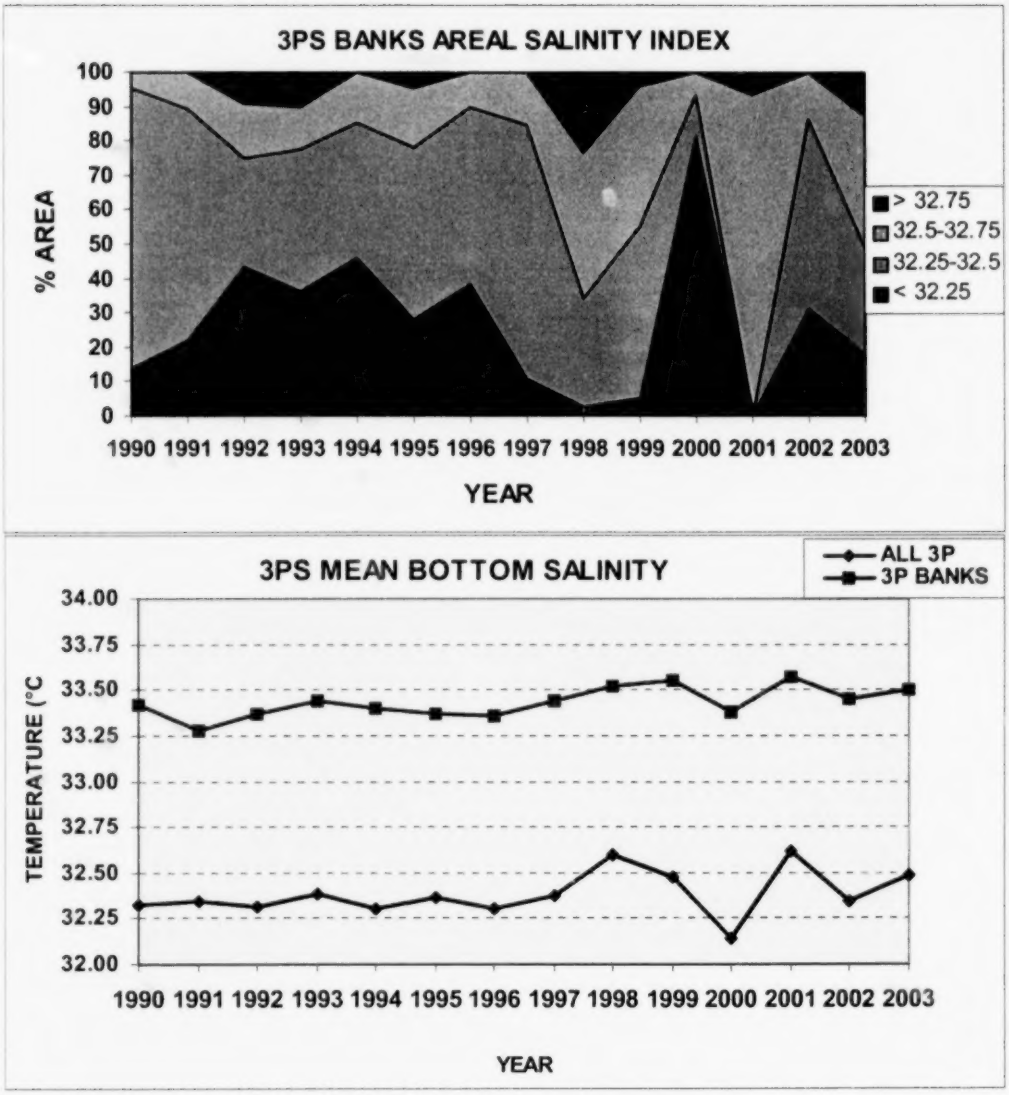


Fig. 8. Time series of the percentage area of NAFO Division 3P for strata with water depths <100 m covered by water in various salinity ranges (top) and the mean bottom salinity for all strata and for strata with water depths <100 m (bottom).

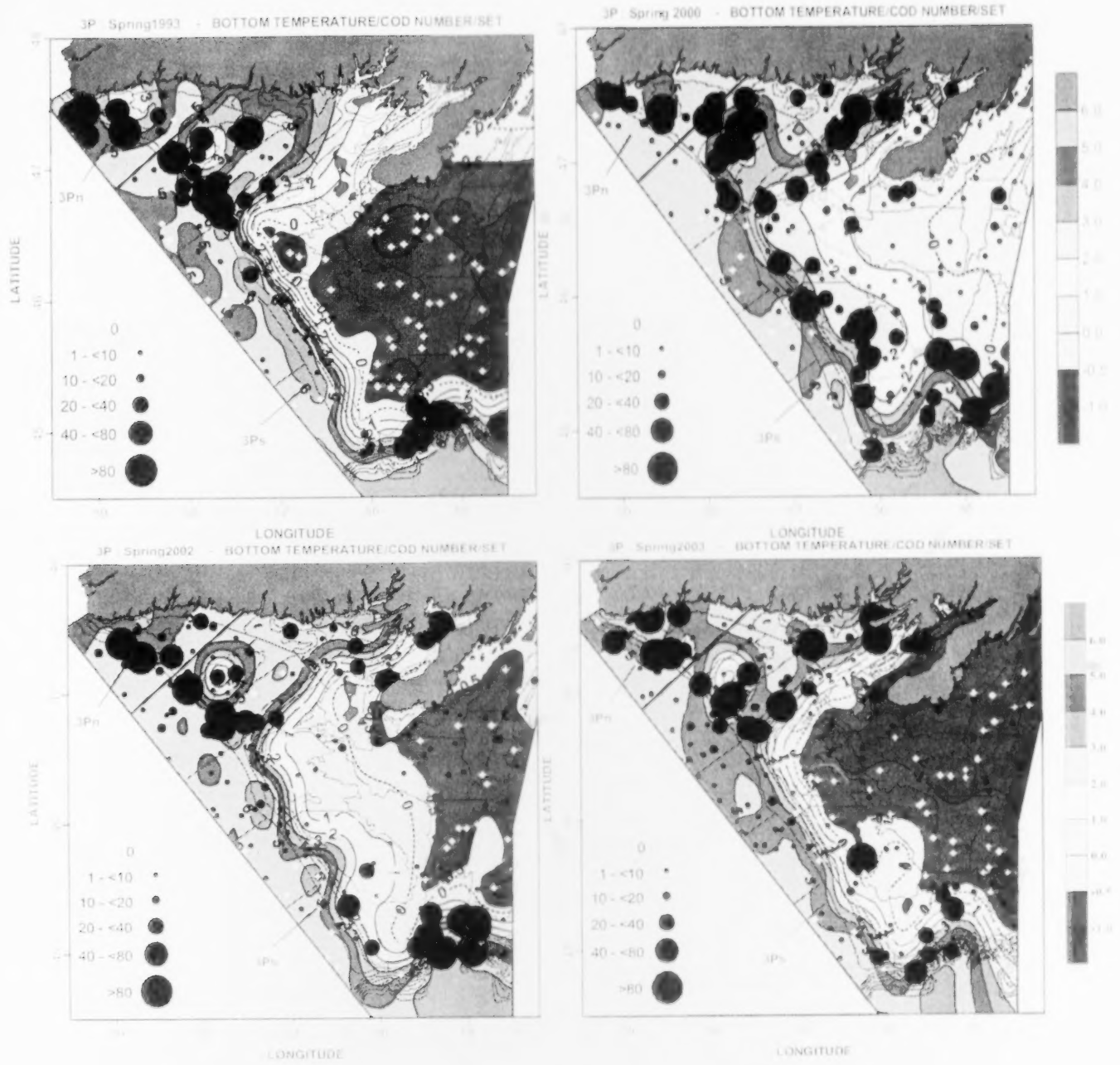
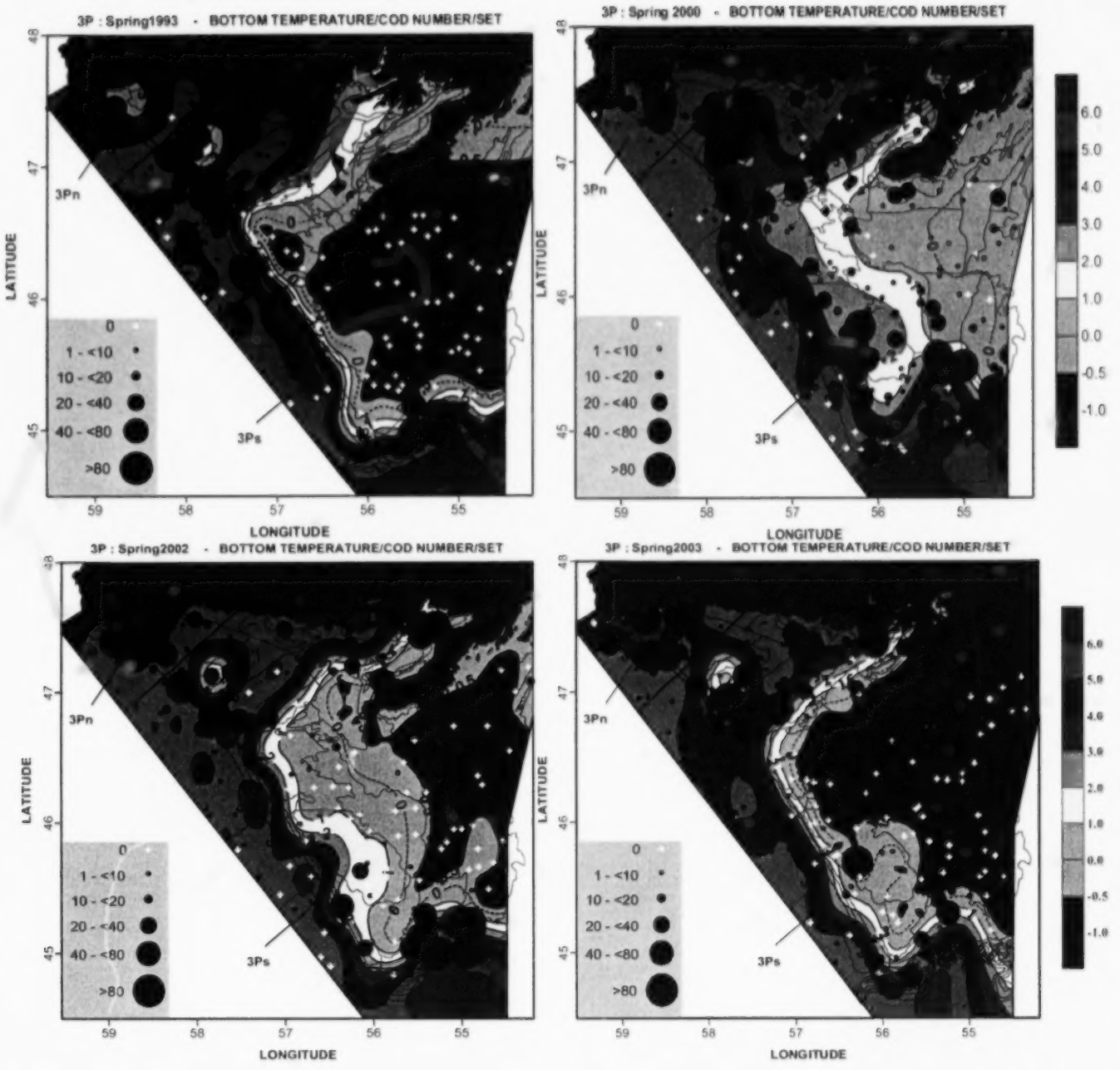


Fig. 9 - Bottom temperature contour maps (in °C) for 1993, 1999, 2002 and 2003 based on data collected during the spring multi-species survey of division 3P. The numbers of cod in each fishing set are shown as solid expanding circles. The white crosses represent zero catches.



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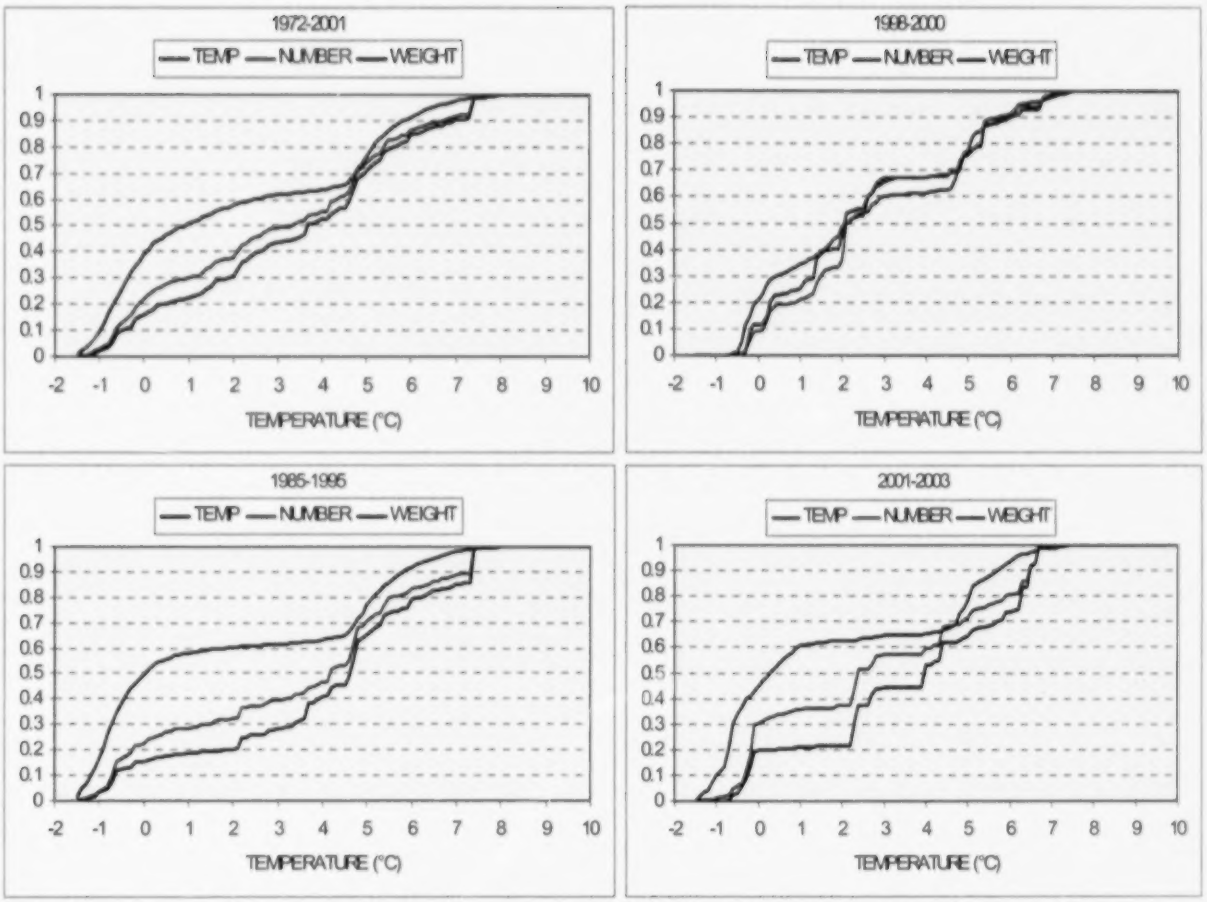

Fig. 10 The stratified cumulative frequency distribution of temperature available to cod and the cod number and catch weighted temperature distributions in NAFO Division 3P for 1971-2001, 1985-1995 a cold period, 1998-2000 a warm period and for 2001-2003.

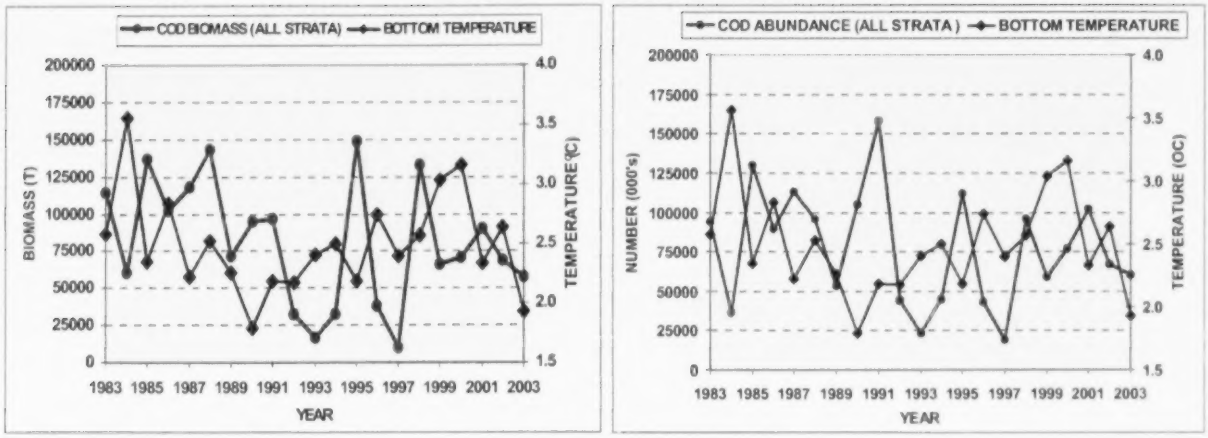

Fig. 11. Time series of the mean bottom temperature and the RV abundance and biomass of Atlantic cod for the surveyed area in NAFO Division 3P.

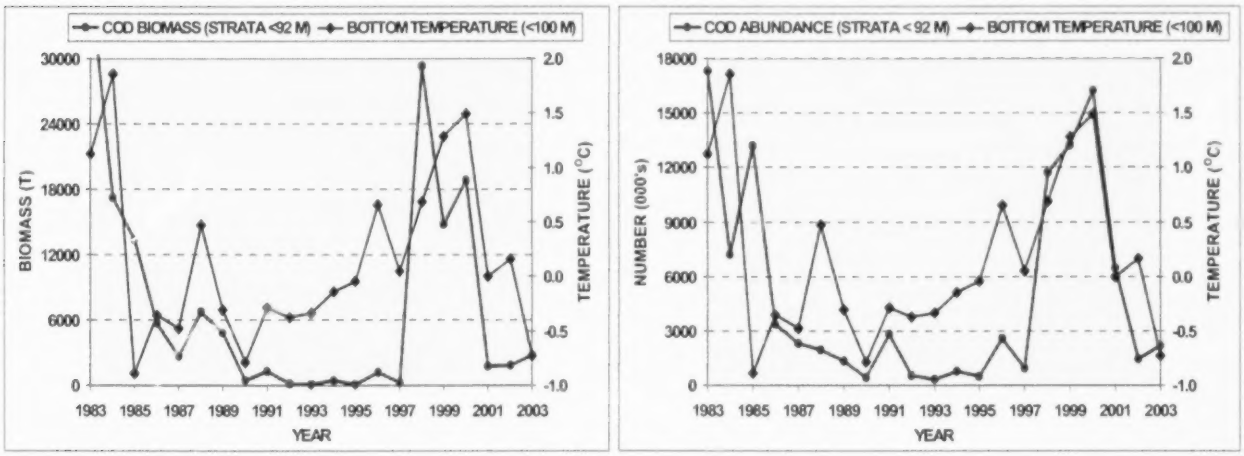

Fig. 12. Time series of the mean bottom temperature for water depths <100 m and the RV abundance and biomass of Atlantic cod for the surveyed area in NAFO Division 3P for strata with water depths <92 m.